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ON EXCAVATIONS MADE IN ROCKS BY SEA-URCHINS.

BY J. WALTER FEWKES.

THE cavities made by sea-urchins in solid rocks were first described at length by Mr. E. T. Bennett[1] many years ago (1825), and since their discovery the phenomenon has been repeatedly mentioned and discussed. The habit is not confined to any single genus, and it seems capable of proof that the same species does not resort to this practice in all localities in which the animal occurs.

The history of the different opinions in regard to the character of the excavations and the means and object of the boring have been considered by others. It is my purpose to barely refer to the historical part of the subject, or simply mention it without further comment. The question has both a geological and zoological, and likewise a botanical side, as the aid of certain low genera of algæ has been thought necessary to account for the phenomenon.

Leske and Linnæus described a species of Cidaris, *C. saxatilis*, but it does not appear that either of them was familiar with the boring habit of sea-urchins. Rumphius mentions the fact that some sea-urchins are found in holes. Lamarck first gave a description of *E. lividus*[2] from a specimen taken by Lalande in the neighborhood of Marseilles, and although he does not mention the excavations made by this species, according to Dr. P. Fisher he had in his possession in 1811 a rock excavated by them.

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[1] Notice of a Peculiar Property of a Species of Echinus. Trans. Linn. Soc., Vol. XV. p. 74, 7, 1826.

Dr. Fisher[3] in 1864 published an historical account of the observations made by others on this subject up to that year. The additions to our knowledge since that time to the present year have been historically considered in a paper by George John.[4] From these two contributions, as well as from the writings on the subject by Bennett,[5] Cailliaud,[6] Trevelyn,[7] Robert,[8] Lory,[9] Deshayes[10] and Hesse[11] a very good idea of what is known on this subject may be obtained.

The boring habit has been observed in the following rock formations: Chalk, coral limestone, limestone, sandstone, gneiss, granite and lavas. It has also been observed in many other rocks, some of which have not been identified.[12] Excavating sea-urchins have been reported from Ireland, England, the Coasts of France[13] on the English Channel, Bay of Biscay, and Mediterranean, Algiers, Azores, Florida, West Indies, Coast of California,

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[2] An attempt by Valenciennes (*Comp. Rend.*, Vol. XLI., p. 743-755) to separate the boring sea-urchin allied to *E. lividus* from the type described from the Mediterranean, under a name *E. tenebrans*, has not been generally followed. The Strongylocentrotus, which makes the excavations at Grand Manan, differs in no way, except possibly that some of the spines are more stumpy, from ordinary specimens which do not bore in rock.

[3] Note sur les perforations de l'*Echinus lividus* Lamk. *Ann. d. Sci. Nat.*, V. Ser., Vol. I. p. 321.

[4] Ueber bohrende Seeigel. *Arch. f. Naturg.*, 55 Jahr, I. Band, 3 Heft.

[5] Notice of a Peculiar Property of a Species of Echinus. Trans. Linn. Soc., 217, 1826.

[6] Observations et nouv. faits sur les Mollusques perforants en general. *Comp. Rend.* t. 39, pp. 43-46. Observations sur les oursins perf. de Bretagne, *Revue et Maz. Zoöl.*, Vol. VIII., pp. 158-179.

[7] Supposed boring powers of the *Echinus lividus*. *Edinb. Philos. Journ.*, 46, pp. 386-87.

[8] Action perforante d'une espece d'Echinoderme. *Comp. Rend.*, t. 39, p. 639.

[9] Observations sur les oursins perforant le granite sur les côtes de la Bretagne. Bull. Soc. Geol., p. 43-46, 1856.

[10] *Ibid.* [11] *Ann. d. Sci. Nat.*, t. VII., p. 251.

[12] John gives a tabular view of the kinds of stone, locality, accompanying organism and observer, made up from his study of the literature.

[13] Fisher has already published a table stating the localities on coasts of France where *Echinus lividus* with excavating habits has been found.

Panama, Australia, Mauritius and Reunion. Not a single instance is recorded from North of Florida on the Atlantic seaboard of North America, with the exception of those from Grand Manan reported in the present paper.

Although it is well known that the sea-urchins of several species are able to excavate holes in solid rock, that habit has not been sufficiently well noted in our common sea-urchin *S. drobachiensis*.[14] It is indirectly referred to in our text-books on Zoölogy, but I have not yet seen a definite statement of a locality on our coast where the excavations can be seen and the boring habit studied. During the past summer (1889) an interesting specimen of rock excavation was observed by the author on the Island of Grand Manan, New Brunswick. A mention of it may not be without value to those interested in this subject or who have in mind a study of the phenomenon. The Black Ledges, which lie near the island of Nantucket, Grand Manan, are rocky reefs bare at low tide and wholly covered at high water. These ledges are made up of a hard mica schist, through which run veins of harder quartzite.[15] These ledges have their surface covered for the most part with "sea weeds" belonging to different kinds of Fuci and Laminariæ, and although not exposed to the full force of the sea from the Bay of Fundy, are still at times beaten by a heavy surf. The sides of the Black Ledges are thus broken or eroded here and there, so that many pools and deep clefts or recesses are forced in them. These recesses are in no way characteristic, but take the form of simple niches in the rock, wholly or partially walled in by the bowlders which lie strewn about, and are often simply natural depressions or basins in the rock. They are generally small, and often have overhanging walls. One of these depressions, which can be visited at low tide only, shows the work of the sea-urchin in rock excavations in the clearest manner. The rock on the sides of which the depressions are formed is inclined at a small angle to a perpendicular, and is almost bare of algæ, so that the boring can be seen without difficulty. The basins ordinarily have water in them at low tide. There is no coralline on the floor of the cavity.

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[14] A. Agassiz states (Revision of the Echini, p. 706) that *Strongylocentrotus purpuratus* has this habit on coast of "California." The kind of rock on which the excavation takes place and the name of the observer not given.

[15] This quartzite is found in several places on Grand Manan in such quantities as to impart a white color to the cliffs, and to it may possibly be traced local names, as White Head, given to a well known island lying off the coast.

The number[16] of sea-urchins at Grand Manan is very great, as was long ago noted by Dr. William Stimpson. In many places it is impossible to see the bottom of the bay, so densely populated is it with these animals. In the rock recess above referred to, the surface of the shelf before the animals were disturbed was paved with sea-urchins, and the number of examples of excavations which they had formed were therefore very numerous. The cavities made by the sea-urchins impart to the rock an appearance not unlike the upper surface of honeycomb, with this difference, that the bounding rim of each excavation is always ring-shaped and entire.

The separate excavations which are shown in the figure, sometimes with the *Strongylocentrotus in situ*, sometimes with the same removed, are never very deep, but are undoubtedly made by the echinoderm. Their surfaces are concave, corresponding with the convexity of the sea-urchin's body, and very smooth, as if freshly cut or worn. They are often larger than the sea-urchin inhabiting them, and roomy enough to admit a free motion of the contained animal. In no instance is the depth of the depression greater than the smaller diameter of the animal. The edge ot the rim which forms a dividing edge between two contiguous excavations is often covered by an incrustation of genera of calcareous algæ.

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[16] The wealth of asteroid and ophiuroid life at Grand Manan is also marvelous to one who has confined his attention to collecting in Massachusetts Bay. The bottom of the passages between the islands would seem to be covered in places with these animals. The dredge near High Duck Island was gorged with specimens of *Ophiopholis aculeata*, with here and there specimens of *Ophiacantha and Ophioglypha*. *Amphiura squamata*, although common, is not found in such multitudes. There is reason to believe from its extreme rarity that the *Comatula* recorded by Stimpson from Grand Manan is a straggler. Certainly the genus is very rare in these waters. *Leptasterias*, *Solaster*, *Crossaster*, and *Hippasterias* were dredged, but they are not common. *Pteraster* also occurs, but is not so frequently found as off Razor Island near Eastport. *Cribrella* is a common Grand Manan genus of starfishes, and a colony of its young, fifty or more in number, were found by M. J. S. Owens on the under side of the rock at low tide near Nantucket. This association in a colonial condition of the young of this genus is an interesting fact, which is probably connected with a want of freedom in earlier stages. *Ctenodiscus crispatus* was not seen by us at Grand Manan, although others have found it there. It was, however, taken at Eastport in subsequent dredging. On the whole the dredging at Grand Manan is not so rich for variety of starfish and ophiuran life as at Easport. The echinoid life is certainly as rich in one place as in another.

Prof. W. G. Farlow, of Harvard University, has kindly identified some of the corallines from specimens of the rock submitted to him. He finds upon them, *Lithothamnion polymorphum* (L.) Aresch., and *Melobesia lenormandi* Aresch. A third kind with papillæ, which he interprets as the beginning of branches, he is inclined to regard a young stage of *Lithothamnion fasciculatum*. He writes me that "the corallines of Northern Europe have been more studied since date of his Marine Algæ of New England, and there may be a question whether the nomenclature of our Eastport species should not be modified to adapt itself to recent work in Artic corallines." The most abundant coralline in the neighborhood of the excavation is the first mentioned. From the sections which I have made of alga, and rock, and a minute examination of the line of contact, I cannot see that the former has in anyway modified the surface of the latter, a result practically the same as that arrived at by John in his studies.

While it is possible that this deposit may in some instances augment the depth of the depression, the amount of such increase is not large, for the alga is generally limited to the top of the bounding rim of the depression, and the walls of its deepest part are filed perfectly smooth, while the sides of the depression and more especially the bounding rim are sometimes covered with and augmented by this encrusting coralline. The surface of the hole as above remarked had no coralline, and generally the rock appeared to be freshly cut.

Hesse records an observation of a sea-urchin boring in oyster shells, and regards this habit as a means of getting food. While it is not impossible that a modicum of nourishment may be obtained in this case by the sea-urchin, it seems to the author improbable that the amount thus obtained can be any considerable quantity. I have learned from good authority (Mr. Cheney) that the spiles of weirs at Grand Manan are sometimes excavated by sea-urchins so that the bark of the birch posts is worn through and even depressions made in the wood tissue. In this instance it may be that the object was food. New observations on this point are necessary, not only as far as the question of excavation in woody fibre is concerned, but also as to the contents of the stomach of those urchins which are found performing this function.

It does not seem to me that the coralline plays any considerable part in the excavation of the rock directly or indirectly, and the sections published by John appear to demonstrate that there is no chemical or other action due to the coralline upon the rock formation upon which it lies. While we would naturally suspect that the geodes[17] once tenanted by urchins might be covered with coralline when deserted by them, in a majority of cases the cavities which are still tenanted have no algous deposit. In those cases where the sea-urchin and the coralline still exist together and in which the surface of the latter is worn by the animal, we may suppose that in the interval during which the sea-urchin had vacated the geode the coralline had taken possession of the cavity, and in due time another sea-urchin had returned to the recess and begun work again upon the layer of calcareous algous formation covering the stone.

My attention was first called to the excavations of Strongylocentrotus by Mr. Webster Cheney, of Nantucket Island, who had discovered them while gunning. Mr. Cheney was not aware, at the time of his discovery, that the fact was known that sea-urchins have their habit of boring in the rocks. I visited the place with a fellow student, Mr. Owens, of Bridgeton, New Jersey.

The following observation was made on the migration of the animal from its excavation, which seems to look as if more than one sea-urchin is concerned in the excavation of a single hole, or that some of the sea-urchins are nestlers as well as borers. It was found, after the sea-urchins had been removed from the excavations which they had made, that in the course of time the holes were repeopled and inhabited by different individuals from those first found there.[18] New individuals thus find the old excavations suited to their purposes, and it is just to conclude that they continue the work of excavation which their predecessors began. They seem to take advantage of the depression already made for their protection.

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[17] The term geode, meaning a cavity, has been used for these excavations. It seems applicable, although used in a somewhat different sense by geologists.

[18] I have, however, no observations to prove that the sea-urchins ever voluntarily leave their cavities for food and after such an excursion return again to them.

It may likewise be supposed that in the case of death, natural or violent, an occupation of the former excavation by a new individual may take place. This is possibly true also in the case of boring sea-urchins from the Azores or the coast of France, where very much deeper recesses are sometimes hollowed in the rock. The fact that the sea-urchin is much larger than the entrance by which it entered the cavity, would thus seem to mean, not that the same individual had hollowed out the entire chamber, but that the sea-urchin which now occupies the cavity had grown larger since it passed through the hole excavated by its predecessor.

An interesting question often asked, and as yet unanswered in a satisfactory manner, is, " How do the sea-urchins make these excavations in the solid rock? " This question is a very difficult one to answer, and several attempts have been made to do so satisfactorily. It is not necessary to mention all the theories suggested, but one or two of the more reasonable may be considered.

Robert supposed that the constant motion of the sea-urchin by which the spines act as files after long attrition has worn out these excavations.

It has been suggested by Cailliaud, and this it must be confessed seems a more reasonable explanation, that the cavities are gnawed or chiselled out by the action of the teeth. Both of these explanations seem possible; but the latter is more probable than the former, as several observations seem to point to this conclusion. Among the facts which support Cailliaud's hypothesis are the following: the teeth are very hard, they have means of repair when their tips are worn, and their surface and cutting points are bare, and well adapted for cutting. It may also be added that the muscles which move the jaws are strong. It would seem, so for as their relative hardness goes, that these organs rather than the spines are the tools which have worn out these holes.

The author believes, however, that Robert was partly right for ascribing to the spines a portion of the work done in excavating the cavities. In sea-urchins taken from rock cavities the spines immediately about the mouth and those on the circumference are somewhat worn in specimens from Grand Manan. Moreover, the surface of the depression is perfectly smoothed in such a symmetrical manner that it seems necessary to suppose a rotary[19] motion of the sea-urchin to effect it. This smoothness, already pointed out in sea-urchin excavations by Trevelyan, could not, I think, have resulted from the teeth alone.

The major part of the work in the excavation of rock by sea-urchins must, however, fall upon the teeth and the dental apparatus. Upon this point the writings of Cailliaud are conclusive. These teeth are probable chisels, which pry into the rock or gouge out fragments, and in that way eventually remove considerable quantities of rock from its bed. A. Agassiz adopts the theory that sea-urchin excavations are chiseled out by the teeth, but offers no evidence bearing on Cailliaud's theory.

John has, it seems to me, furnished important data, indicating that the teeth play a part in the wearing out of the rock cavities in which the urchins live, for he was able to find in the alimentary canal of the sea-urchin fragments of stone similar to that in which the borings were made. The simple fact, however, that grains of rock similar to those of the locality of the sea-urchin are found, is not in itself an evidence that they were chiseled out of the rock by the teeth. We know that toothless Echinoidea, as for instance genera of Spatangoids, often have their alimentary canal full of sand, which has apparently been swallowed by the animal. There seems no reason to refuse to believe that any of the so-called round sea-urchins are not able to swallow small pebbles in the same way, but while it is true that the one (spatangoid) generally lives on the sand, and the other (echinoid) on rocky bottom, one can readily see how small fragments might be picked up by the latter and swallowed.[20]

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[19] This rotary motion is yet to be observed, but it may be said that if it exists it must be very slow, as the animals never move rapidly.

[20] Sea-urchins are at times scavengers, or at all events a carcass of a seal sunk in the water will be found to be covered with these animals. Possibly they feed on the sea fleas and other animals which do the work of scavengers.

We have members of almost all the lower groups of animals, as sponges, annelids and other worms, mollusks and crustaceans, all of which are endowed with boring habits. The excavating habit possessed by the sea-urchin may belong to the same category as that of these animals, and it may be a voluntary act for self protection or other purposes. There is, however, this very interesting fact pointed out by others in relation to the boring sea-urchin, in which it seems to differ from those already mentioned. The habit of excavating seems to be one which is limited to individual sea-urchins which live in certain exposed positions, where the tides are very high. Thousands of specimens of sea-urchins on rocks where there was not a visible sign of excavating can be found, and those echinoderms which are below the wash of the tide, as well as some in its force, exhibit no manifestation of this power. These facts lead me to ask if it is not possible that there are influences in environment or in physical forces acting upon them which make certain individuals an involuntary agent in boring. Or is it not probable that we may find the excavating power due in part to the action of the sea itself. It is in other words possible that the force which excavates these geodes is somewhat similar to that exerted in the case of the formation of the geologic phenomenon known as "pot-holes." The living body of the sea-urchin might occupy the same relation to the cavity in which it lies that the inert stone does to the pot-hole in which it is often found, and which it played an essential part in creating. The fact that beautiful examples of pot-holes can be seen worn out of the solid rock on the adjoining island of Grand Manan, not far from the sea-urchin excavations, has suggested this explanation, which certainly has much to recommend it. We may, if we adopt this theory as a part of the explanation, regard the echinoid body clothed with its spines as an involuntary agent moved about by the waves, slightly perhaps, yet moved enough to wear out by its attrition in course of time the solid substance of the rock. The spines, teeth, and possibly the body itself may thus exert a wearing action capable in time of making an excavation into the solid rock. This explanation would furnish good reason for the very smooth character of the floor of many of the sea-urchin hollows.

One can readily imagine how in the beginning of the growth of the cavity, in order to cling more tenaciously to the rock, the sea-urchin seeks out a small natural depression in which it anchors itself by its suckers for protection from the surf. Constant movement of its body, due to the waves, and consequent attrition of the spines and teeth, caused by the movement of the water, deepens this slight depression until it reaches a considerable size, which is enlarged by every motion of the animal. To this increase in size voluntary movements of teeth and spines also contribute.[21]

The accompanying figure taken from a photograph by Mr. Northrop, of the School of Mines, New York, represents a number of these sea-urchins as they naturally lie in their excavations, and also several cavities, formerly occupied, from which the inhabitants have been removed. Although these holes are not so deep and therefore not so conspicuous as can be seen in rocks from some other coasts which might be introduced in illustration, they are the only ones which I have ever seen from our vicinity which exhibit this phenomenon.[22]

I am tempted to return to an aspect of the subject to which I have already alluded. Notwithstanding the large numbers of sea-urchins found at Grand Manan, the places where the excavating habit can be studied are very few in number and very local. I know indeed of no other locality except on the Black Ledges where there are excavations of this kind, and yet there are many places where the conditions are identical, and where the animals are equally abundant. It may be concluded from these facts that there must be certain peculiarities of environment especially adapted to these animals to present favorable conditions in individuals for this habit. It would seem that a mechanical explanation that the depressions were in a way due to forces analogous to the action of those at work in the excavation of "pot-holes"

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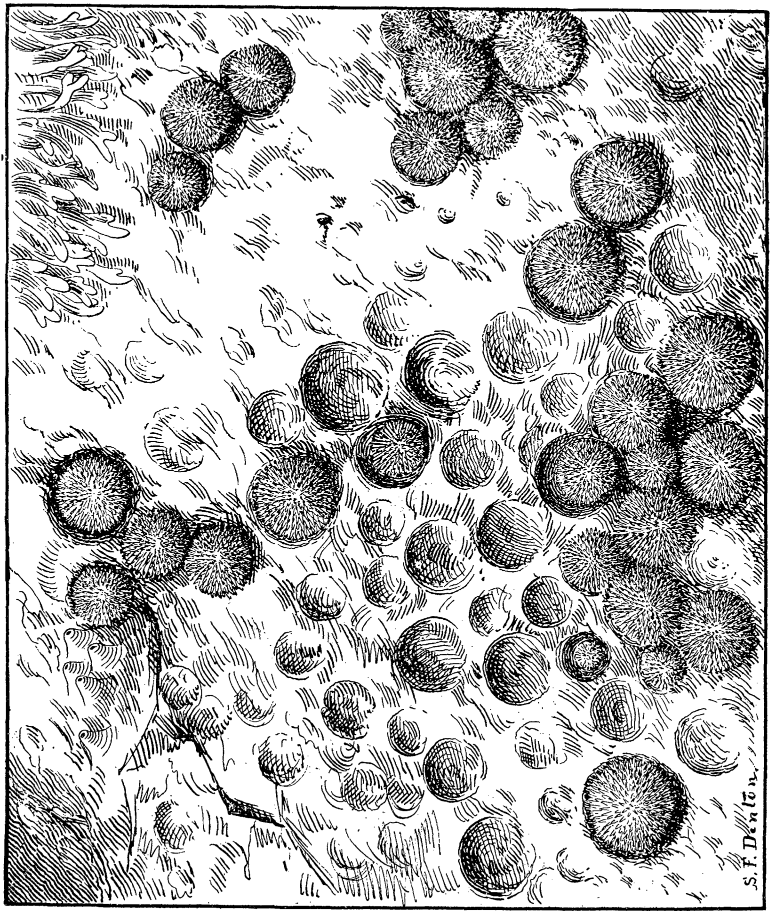
[21] James Salter. On the Structure and Growth of the Teeth of Echinus. *Quart. Journ. Micr. Sc.*, 1861, p. 216.

[22] The fact that specimens illustrating the excavating power of the sea-urchins can be seen on our coast is an interesting one as affording an opportunity to study the method by which the sea-urchins accomplish their work.

PLATE I.



BURROWING ECHINI.

The above figure was taken from a photograph of a part of the side of the grotto in which the sea-urchins are found. The photograph was kindly taken for me by Professor Northop of the School of Mines, New York City, to whom I am indebted for this and other kindnesses.—(*See page 10.*)

affords in a way a harmonious explanation of the extreme rarity of these excavations on the coast of an island densely populated by sea-urchins. There seems no satisfactory reason why, if the process of excavating is simply a habit, we should find it so rarely exhibited. It is true that some species of mollusks sometimes excavate and sometimes do not, but while it is not improbable that there are many localities on our coast where specimens to illustrate this process may be found, they are certainly not as numerous as we might justly suspect they might be if the power of excavating was a voluntary one alone, and not in some way connected with forces acting about them. It likewise seems as if, knowing as we do that the habit of boring in rocks is found in those animals where the process is wholly voluntary, we might ascribe the habit in sea-urchins to the animal itself. We are at a loss to explain why sea-urchins make excavations only when they are in certain places and under certain conditions.

This peculiarity has already been noted by Deshayes in regard to *Echinus* (*Strongylocentrotus*) *lividus* on the two shores of France, and needs a further study.[23]

Dr. George Dimmock informs me that he has seen these excavations at Banyuls-sur-Mer. As these excavations exist on the shore of the Mediterranean, the suggestion that the excavations are limited to rocks beaten by a heavy surf or where there is a large tide would seem to be unsupported. Still, in a general way, the excavations made by sea-urchins are greater and more numerous on coasts beaten by a strong sea, and where there is a considerable tidal variation.

A theory that the work of excavation is in part assisted by acid secretions from organs of the body, feet, or mouth, does not seem plausible, or at all events requires more decisive observations than have yet been brought to its aid. The excavations are in all kinds of rock, and it seems improbable that a secretion could be made by them which would act on lava, limestone, slate and granite. The same may be said also of the supposed power of the suckers of the ambulacral feet or the other soft structures of the body. Until more facts are advanced in support of these theories we can hardly accept them as well founded.

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[23] According to Fisher, Lalande found them near Marseilles, while Arthur Eloffe, Marcel de Serres and Cailliaud have observed or recorded sea-urchins in holes near the lighthouse of Planier, also on the Mediterranean.

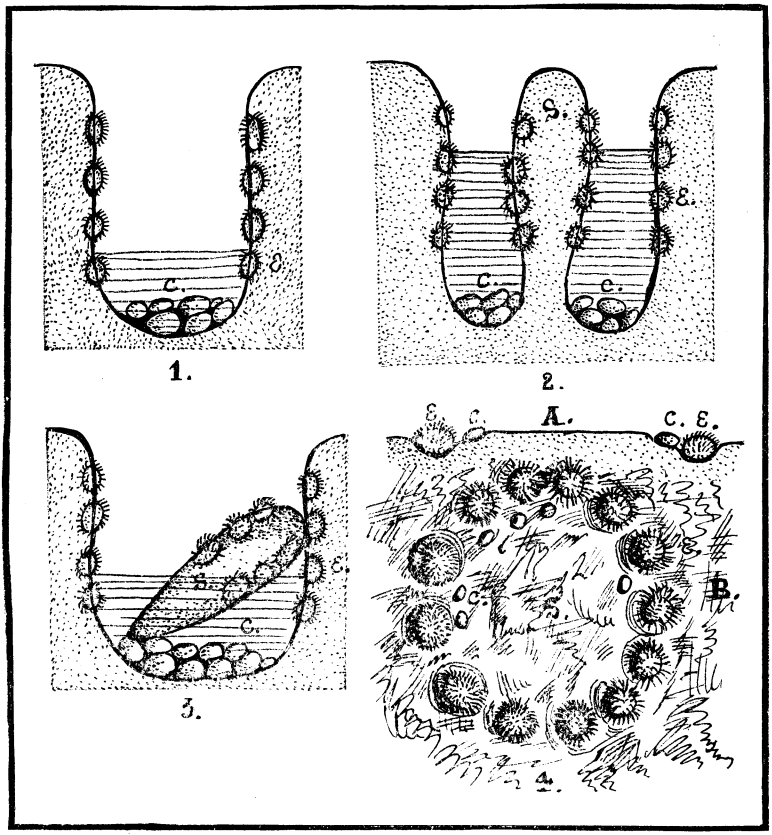
Either the calcareous spines, the wall of the test, or, most important of all, the teeth are singly or together the agents which have produced these excavations. It seems to the author plausible that mechanical movements of the sea-urchin by the waves, in combination with voluntary action, has played some part in the formation of these cavities. It might facilitate our framing a satisfactory answer to the question if we knew whether or not the matter worn off from the surface of the sea-urchin excavations was always passed into the alimentary canal. An examination of the stomachs of sea-urchins which inhabit these excavations might by following John's method throw light on this question. Unfortunately I have nothing to add to what is already known bearing on this subject.

An interesting example of erosion and the excavating habit of the sea-urchins has been called to my attention by Prof. Jules Marcou, of Cambridge. At my request Professor Marcou has kindly written out his notes, which have never been published, and are consequently quoted entire in the following pages :

"PERFORATIONS DU CALCAIRE SABLEUX NUMMULITIQUE INFÉRIEUR PAR L' *Echinus lividus* DANS LES ROCHES DE HALDE À BIARRITZ.

" Entre le vieux Port de Biarritz et la côte des Basques, s' advance la Pointe des Roches de Halde, toujours très fortement battue par les vagues ; à basse marée l' extrémité de la Pointe se découvre sur une longeur moyenne de 75 pieds anglais (25 metres) ; et au milieu d'algues diverses on trouve tout une population littorale (Moules, Patelles, Littorines, Actinies et surtout des Oursins). L'oursin est l'espéce commune tout le long de la côte de l'Atlantique, *Echinus lividus* Lam. ; non seulement cet oursin se creuse une niche dans laquelle il vit, mais bien plus il agit en corps pour se créer une habitation collective.

PLATE II.



Diagrams of Sea-Urchin Excavations at Biarritz,

(Jules Marcou, del.)

A few words in explanation of the diagram may lead to a better comprehension of them. Fig. 1 represents a pot-hole partially filled with water, on the walls of which sea-urchins (*e*), can be seen; at the bottom of the pot-hole there are small stones (*c*); the breadth of these pot-holes is indicated by Professor Marcou as one and one-half feet, the depth, two feet. Fig. 2 shows a stylated pot-hole; and Fig. 3, a pot-hole in which the style (*s*) is broken off and appears as a stone, somewhat larger than the other (*c*). On the large stone the sea-urchins can be seen clinging in their canties. Fig. 4 has two parts: *A*, which shows a section of the rock on which, when seen from above, the sea-urchins are arranged in a ring. These sea-urchins are sunk in depressions, while centripetally to them appear the small stones, (*c*), which are supposed to form the annular depression about the style (*s*); *B* of Fig. 4 represents the ring of sea-urchins on the surface of the rock, seen from above.—(*See page 13.*)

" On voit dans le calcaire sableux des espèces de marmite ou de mortier, tous habités par cet oursin, et dont voici les divers états, lorsque je les ai observé, à la marée basse le 8 mai, 1876.

" Tout à fait à l'extrémité des Roches de Halde, là où l'eau reste dans les anfractuosités, les depressions et les marmites, au milieu d'algues très épaisses; on rencontre:

" 1. [25] Des trous ayant de un pied, à deux pieds de profondeur au maximum, et de un pied à un pied et demi de diametre, en forme de marmite; au fond on voit des cailloux trés arondis et usés, qui à chaque marée sont fortement agités par les mouvement violent de l'eau, qui déferle toujours avec une grande force sur toute la Pointe de Halde et recoivent ainsi un mouvement circulaire, qui les fait creuser de plus en plus la marmite où ils se trouvent. Chacune de ces marmites est occupée par plusieurs rangs d'oursins, étagés les uns au dessous des autres, sur trois, quatre, ou cinq ligues; et chaque oursin occupe une niche de deux a quatre centimetres de profondeur, qu'il a creusé lui-même avec ses piquants dont il se sert comme d' une lime.

" 2. La marmite ou mortier a quelquefois au milieu une colonne solide de calcaire.

" 3. La colonne du milieu fini par être usée à son pied par le mouvement continuel de rotation des cailloux accumulés au fond de la marmite et j'en ai vu un example avec la colonne detacheé et gisant comme un pilon au fond d'un mortier, comme la figure ci-joint. Les echinus sur la colonne isolée et qui agissait alors en tournant comme les autres cailloux roulés, étaient vivants et ne paraissaient pas être incommodés par le mouvement de rotation auquel ils étaient soumis, deux fois par 24 heures.

" 4. Enfin j'ai vu un commencement de marmite. Des oursins s'étaient placés sur un espèce de cercle et y avaient creusés leurs niches; quelque petits cailloux detachés commençaient leur office de creusement du calcaire pour arriver à créer une station-marmite pour les échinides.

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[25] Each of the above-mentioned conditions is illustrated by a diagram bearing the same number. These diagrams are copied from drawings which Prof. Marcou has kindly made and sent to me, and convey very well the peculiarity of these remarkable excavations.

"Comme aspect chacune de ces marmites avec sa population de 40 à 60 Echinus, et peut-être plus, resemble à une façade de maison avec un habitant à chaque fenêtre ouverte et qui seraient occupés à regarder ce qui se passe. Tous les échinides étaient bien portants, et je n'en ai pas vu de mort.

"JULES MARCOU."

According to Fisher, Cailliaud says that excavations by sea-urchins were observed at Biarritz by MM. Sæmann and Cazenavette. This was probably the first observation of this habit in this locality, but I am unable to discover from Cailliaud's account that the peculiar relation to pot-holes was noticed by them, or by any author quoted by him in the preparation of his paper.

It is remarkable that such an interesting case of erosion should have escaped their observation, a fact which may be ascribed possibly to the inaccessible position in which these rock erosions were to be found. Marcou was engaged in collecting fossils when the pot-holes were discovered, which led him to portions of the coast not easily visited.[26]

Fisher also observed that the common sea-urchin at Biarritz has the habit of excavating, although the relation of these urchins to pot-holes in that locality seems to have escaped his notice. He writes: "A marée basse une grande partie des rochers du Port-Vieux sont émergés et rejoinnent quelques blocs plus élevés, placés au large, qu'il serait facile de relier par une jetée. La mer bat vigoureusement contre des roches plus résistantes que les falaises de la côte des Basques; le sol du port est un sable très-fin. . . . Quand on examine les rochers á marée basse, on trouve au-dessous de la ligne d'émergence des excavation sprofondes, de grandeur variable, depassant quelquefois un mètre carré en superficie. Jamais ces excavations ne manquent d'eau, lors même que leur contour émerge à l'époque des grandes marées; leur profondeur permet á la mer d'y laisser au moins un décimetre d'eau. C'est dans ces sortes de cuvettes que vivent les oursins (*Echinus lividus*, Lamk.) parqués par groupes de vingt-cinq á cent disposés dans un ordre admirable, possédant moins un trou; leurs excavations sont tellement rapprochées, qu'il est impossible à d'autres oursins de conquérir une place dans la colonne.

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[26] At the time of his visit Prof. Marcou was not specially engaged in a study of the work of these animals, but the examples of rock erosion were so striking that his attention was attracted to them, and he retains to-day thirteen years after his visit, a vivid memory of them. On his return to America he called the attention of several persons to his observation, but nothing was published, and apparently no great interest was excited in them.

"La position des oursins est invariable; la bouche reste appliquée en bas, au centre du trou; l'anus est par conséquent en haut. A l'époque de mes observations (août, 1863), les oursins gardaient une immobilité compléte, les radioles étant redressées; ils s'engageaient si bien dans les excavations, que souvent leur extraction m'en a paru impossible.

"Je n'ai pas aperçu d'oursins sur des roches émergées et privées d'eau; et partout où j'en ai trouvé, ils étaient logés dans des trous particuliers."

From the above quotation, which is but a part of the description which Dr. Fisher gives of the work of sea-urchins at Biarritz, it is evident that he carefully studied these excavations at this point, but neither from this description nor from the remainder of his account am I able to find that the peculiar relation observed by Marcou between sea-urchins and pot-holes was seen. He makes a minute comparison with the perforations found at Biarritz of a number of specimens, which at the time of his writing existed in the Museum d'histoire Naturelle at Paris.

It may not be out of place to call attention to certain peculiarities in sea-urchin excavations suggested by Prof. Marcou's notes. From the observations it seems that veritable "pot-holes" were found at Biarritz in which there is a central column of rock, which is unlike in its relationship to the pot-hole to the columella to the cup of certain corals. This central axis or style he supposes to be formed by the wearing away of the rock about it, by which it is left standing as a pinnacle.[27]

Prof. Marcou believes that the first stage of development of the ring-shaped stylated pot-hole is due to the sea-urchins excavating in a ring-shaped depression (Fig. 4, A. and B.) enclosing the central area. The animals are assisted in their work by the presence of small stones (*c*), which have been washed in by the waves. An interesting observation in relation to the sea-urchins is that on the inner surface of the pot-hole there are many small excavations worn by the sea-urchins (*e*). Each sea-urchin is lodged in a cavity which it has worn out. Moreover, there are also similar holes (Fig. 2) excavated by the sea-urchins with the animals still in them on the central style. The Echinoids occupied their supplementary excavations when they were seen by Prof. Marcou, and the cavities are so shallow that a small part of the body of the sea-urchin projects beyond the level of the rim of the hole. The position is certainly exceptional, but not less remarkable than the fact that we have a pot-hole with a central columella.[28] Prof. Marcou also observed "pot-holes," and the surfaces of the enclosed stone (*s*) were tenanted with sea-urchins which were found in slight depressions. The size of the enclosed stones would seem to imply that they are due to a breaking away at the base of the central style of the first kind, and not that they were the active agents in wearing down the inner surface of the pot-hole.

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[27] It is of course necessary to know whether this pinnacle is of the same rock as that which bounds the "pot-holes," and not a concretionary structure. Prof. Marcou has furnished the desired information, for he says that the style is of the same kind of rock as that in which the pot-hole is worn.

The first type (Fig. 1) of pot-holes with sea-urchins, which were observed by Prof. Marcou, may be nothing more or less than ordinary "pot-holes" in which the wearing stone is found at the bottom. They are interesting as possessing supplementary cavities worn in the sides by the sea-urchins. This type may have been either derived from the third (Fig. 3), that with a larger enclosed stone, which itself came from the stylated (Fig. 2), or it may have been developed, as in the case of ordinary pot-holes which do not have the stylated axis, by simple grinding resulting from the movement of the stone. It can readily be seen that the third instance (Fig. 3) mentioned by him is derived from the second (Fig. 2), and that the second may have been derived from the fourth. The first, however, may have been formed as all simple pot-holes, by the rocks or pebbles within it, as ordinarily explained by geologists. It may, of course, have been formed from the third by repeated grinding of the rock without the sea-urchin contributing any help.

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[28] It certainly cannot be supposed that the pot-holes with a central pinnacle of this kind are formed in the same way as ordinary kinds.

The statement that the sea-urchins are arranged in stories is an interesting one. I am unaware that a similar arrangement has ever before been observed, and I have never seen similar examples of the arrangement of sea-urchins in a ring, as observed by Prof. Marcou, and described by him in the fourth instance (B, Fig. 4).

The wearing away of the zone of rock, leaving the central axis (*s*) standing, is certainly a remarkable case of erosion, unlike any which has been recorded.

The explanation advanced to explain the central style is certainly an ingenious one, and should be investigated by those naturalists who visit Biarritz. The hypothesis that the sea-urchins bore in the solid rock a ring of excavations, the walls of which were broken down by the small "cailloux" (*c*), seems plausible, but why the sea-urchins should arrange themselves in a ring (B, Fig. 4) is not wholly clear to me. It is a well known fact that sea-urchins have a habit of getting together bits of sticks, algæ shell, etc., by which they cover themselves. Those that live on sandy sea bottom, as our common clypeastroid Echinarachnius, crawl under the sand in order to hide themselves. [29] The boring sea-urchin possibly collects the stones for this purpose, which, dropping off, fall down between the sea-urchins, and by their grinding action serve to enlarge the depression. The stones, however, are too large to be placed there by the sea-urchins, and it is probable that they were simply caught in the depression after having been thrown there by the waves.

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[29] I have observed on the Florida Reef an interesting case of the inclusion of an Echinoderm by the growth of coral about it. This phenomenon is not a rare one as far as other animals of various groups are concerned, but there is reason to believe that the inclusion of an Echinoderm by growing coral is not common. At all events I am not familiar with a printed record of this fact. The inclusion takes place by a simple growth of the cœnosarc around the urchin, leaving the animal in a cyst, which is in free communication with the external water through a small opening. This imprisonment of a sea-urchin by a growth of coral cœnosarc is in its results not unlike the excavating habit of the sea-urchin, and may have been mistaken for it. The conditions, however, are readily distinguished from each other, and the process by which both are brought about is radically different. In both instances we probably have a means of protection of the animal from the waves. I am informed by Mr. C. H. Maynard that sea-urchin excavations on the Bahamas are tenanted by a genus of Chitons. This mollusk may not be a commensalist, only so far as to seek the protection of the hole from the surf. Mr. Maynard likewise finds a small fish inhabits these sea-urchin excavations, and he tells me that when alarmed the fish hides among the spines or under the body of the sea-urchin. This is a phenomenon somewhat like the habit of hiding under stones which has long been known in Lepadogaster and the "butterfish," and other fishes, and can hardly be interpreted as an instance of commensalism.

Prof. Marcou has furnished the following directions for those who would examine the interesting pot-holes which he has discovered at Biarritz :

South of "le port Vieux" there push out to the west into the sea at least three peninsulas, separated by parallel bays. The road to the Côte de Basques runs at the base of these peninsulas, on the eastern edge. The pot-holes were observed at the western end of the most western of these peninsulas. The locality is rich in fossil echinoidea, serpulæ, and other animals.

The question of why and how the sea-urchins bore in the rock seem to have been answered in as many ways as the number of observers. The sea-urchin excavations at Grand Manan have certain resemblances to and differ somewhat from those recorded by others. My interpretation of their cause, as derived from their study at this locality, also differs somewhat from those of other observers. As to the question why the sea-urchins make these hollows there seems at least two answers. Their main object is probably for protection from the waves, as has already been shown by several naturalists. At the same time that the depressions serve for protection, they would form receptacles for water, which would be of great use to the animal between tides. [30] Ordinarily not much water would be retained in that way, but in the case of the pot-holes at Biarritz it would be considerable in amount, and natural aquaria with a continual supply of pure water would be at hand. Prof. Marcou has aptly compared the situation of these colonies of sea-urchins on the walls of a pot-hole to a hotel with guests. The simile, though fanciful, may not be far from the truth. It is a significant fact that sea-urchin excavations where the tides are small, as in the Mediterranean, are also not very large.

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[30] Marcel de Serres (Sur l'action perforante de l'*Echinus lividus*. *Comp. Rend.*, Vol. XVIII., pp. 405, 406) tries to explain the rarity of sea-urchins' excavations on the coast of the Mediterranean by the absence of the ebb and flow of the tide.

The almost universal presence of a calcareous alga on the rim of the sea-urchin boring might seem to indicate that there is a symbiosis between the alga and the animal. It would seem as if the rim was built up, in part at least, by the alga, as a protection for the sea-urchin, and that in return the alga received certain advantages. In the case of very deep sea-urchin excavations this would not hold, as there can be no doubt that the cavity is made by the urchin boring in the rock.[31]

Among other statements which might well be quoted, Caillaud reaches the following conclusion, which is very significant Speaking of rock excavations, and of the buccal armature, he asks, "S'il n'était pas dans la nature de ces êtres de creuser des roches, pourquoi seraient-ils ainsi pourvus et outillés de poinçons en émail dont les sommités s'usent, puis se renouvellent, se cracourcissent dès lors et doivent, de toute nécessité, recevoir le prolongement nécessaire pour conserver leur longueur voulue tant que l'oursin travaille? Si cet appareil," he continues, "si bien combiné pour agir sur la pierre n'avait pas ce but, il deviendrait inutile à cette tribu de veritables Echinus que en sont pourvus; ils auraient reçu des simples dents fixes et ordinaires, comme tant d'autres dans cette immense famille, comptant, comme nous l'avons dit, en vivants et fossiles, seize cents espèces. Comme example, nous citerons particulièrement le genre Clypéaster, à qui tous les moyens de perforer les roches sont interdits."

It is interesting, taken in connection with the above quotation, to speculate as to the character and use of the "Aristotle's Lantern" in the Clypeastroids, and its absence in the Spatangoids. The lantern of the genus Echinarachnius is so small and inconspicuous that it is difficult to believe that its function is the same as in the round sea-urchins, or echinoids. Moreover the manner of life of this genus is such that we can hardly suppose that there is any need of a complicated buccal apparatus such as is found in Strongylocentrotus. One is even tempted to regard the lantern in Echinarachnius as a rudimentary organ which has lost its functional importance.[32]

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[31] Deshayes does not accept the view that the sea-urchin bores in the rock. He regards them as simply seeking out excavations already existing. He finds first that it is without example elsewhere in the animal world that the same species on one coast bores holes, and on another does not. Secondly, the habit once acquired would be universal for individuals of the same species. Thirdly, the sea-urchins have no organ for boring, and, lastly, the holes are covered with calcareous algæ. These views have been discussed by others. I think, in answer to the first and second objections, we may say that the wave motion brings it about that individuals in one place bore, and in another do not.

While it is next to impossible to say how much or how little of the excavation is due to any one of the three means of wearing away of the rock, the teeth, spines, and wave action, we can safely conclude that the most important factor in this work is the dental apparatus. Next in importance are possibly the spines, while last of all comes that work done by the rolling about of the sea-urchin due to the motion of the water. To the general proposition advanced by John, we might also add that there is evidence that the time which has elapsed between the inception of the sea-urchin's work in excavation and the present condition of the cavities is probably much larger than the life of the individual which now occupies it. In an interval between two occupants the interregnum may have been filled out by effective grinding out of the cavity by the motions of the test of the former occupant, or by fragments of the spine, the teeth, or other hard parts of the dead animal which has left this heritage as a means when moved by the water to grind out the excavation for its successor.

After a somewhat extended discussion of the views of others, John gives as his conclusions in regard to sea-urchin excavations the following summary:

" Die in den Gesteinen gefundenen und von Seeigeln bewohnten Höhlen rühren von diesen selbst her. Der Echinus erzeugt seine Wohnstätten mittelst seines Kauapparates und sekundär mit Hilfe der Stacheln durch rotierende Bewegung. Er bohrt sich solche Höhlungen, um einen Schutz gegen das brandende Meer zu haben.

" Die Kalkalgen, welche die von Seeigeln bewohnten Gesteine bedecken, lagern sich mechanisch auf das Gestein und haben keinen Einfluss auf die chemische Beschaffenheit der Oberfläche desselben, kömmen daher auch nicht mit dem Entstehen der Echinushöhlen in Zusammenhang gebracht werden."

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[32] It seems to the writer capable of proof that the flat sea-urchins are structurally lower as far as their internal anatomy goes than the so-called " round sea-urchins." Still that proposition would not be accepted by one or two prominent special students of these animals, and this does not seem the place to present arguments in its support, or to combat objections which might readily be made to it.

The above conclusions are substantially those to which the author has been led by a study of the sea-urchin excavations at Grand Manan, except that he would also adduce the motion of the sea as an additional factor in the excavation of these cavities. By this wave action the sea-urchin covered with spines is moved about, rubbing against the wall of the cavity in which it rests. A continued action of the spines and other hard parts of the animal on the rock thus deepens the depression at the same time that it files the surface smooth.

SUMMARY.

The results of the preceding pages may be briefly stated as follows:

1. *Strongylocentrotus drobachiensis* on the coast of Grand Manan sometimes makes excavations in solid rock.

2. The excavations are made by the sea-urchin by means of its teeth, spines, combined with motions of the animal produced by waves and tide. The object is primarily for protection, but secondarily a sufficient amount of water is in that way retained by the animal during half tide, or when otherwise uncovered.

3. The coralline accompanying the sea-urchin, generally found at the rim of the excavation, takes no part in the formation of the recess, although its presence may be necessary to the animal for some unknown reason.

3. Sea-urchins are found at Biarritz, France, which live in stories on the walls of peculiar pot-holes, some of which have a central style also tenanted by the same animals in small depressions.

5. The sea-urchins play some part in the formation of stylated pot-holes, although they are assisted by the movements of stones, produced by the action of tides and waves.

Boston, January 1st, 1890.